# Technical Specifications for the ESS MEBT FC

# MEBT-BI-FC90-03

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## 1. Object

The purpose of this document is to define the technical specifications for the Faraday Cup, which must be delivered by the contractor. The Faraday Cup is part of the MEBT that ESS-Bilbao will deliver as part of the "in-kind" collaboration to the European Spallation Source project.

ESS Bilbao will supply a Conceptual Design as a CAD 3D model, which should be taken as the base design for the Detailed Design.

The scope of this contract is:

- Detailed Design of Faraday Cup.
  - Revision of the Conceptual Design and proposal of changes. The components proposed in the Conceptual Design can be considered as a recommendation. Any change must be approved by ESS-Bilbao before blue prints production.
  - Blue-Prints, description of materials and method of fabrication of pieces or components to be manufactured by the contractor.
  - Technical characteristics of commercial components that the contractor orders to a third-party company.
  - Study of manufacturing procedures based on the specification given on this document.
  - The Detailed Design will be reviewed by ESS and ESS-Bilbao. After approval of the Detailed Design the contractor will proceed to manufacturing of the Faraday Cup.
- Product manufacturing:
  - Machining and manufacturing of components, purchase of commercial components and product integration.
  - The product will be manufactured according to the design approved in the Detailed Design. Any modification taking place during the manufacturing process will require ESS-Bilbao approval.
- Testing and delivery.
  - The product will comply with the acceptance plan described in *"Section* 3 *-Acceptance Plan"*.
  - Complete documentation of the manufacturing procedures, product components and materials specifications will be supplied with the final product.
  - Cleaning, packaging and shipping to ESS-Bilbao.

## 2. Technical Specifications

ESS-Bilbao is in charge of the design and manufacturing of most of the European Spallation Source Medium Energy Beam Transfer Proton Beam Instrumentation (ESS MEBT PBI).

One of the components of the Proton Beam Instrumentation is the Faraday Cup (FC). The Faraday Cup measures the beam current with high accuracy. The FC will be used for calibration purposes during the ESS commissioning, and under specific beam modes.

In Figure 1 we show the Faraday Cup and its main components. The conceptual design of the Faraday Cup is given is given in the CAD model attached to these technical specifications[1].

In Table 1 the main design parameters of the Faraday Cup are summarized. In the next sections full description of the Faraday Cup and its requirements is given.

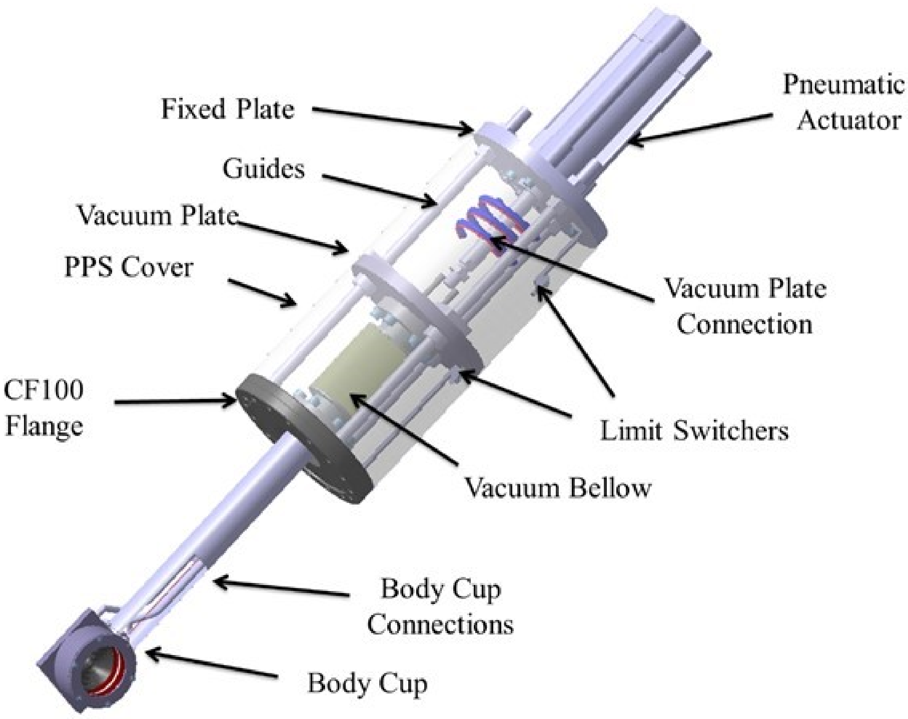


Figure 1: Scheme with the main components of the FC design.

[1] The figures used in this document may not correspond completely to the supplied CAD model. In that case the CAD model should offer the last version of the conceptual design. In case of doubt please contact with ESS-Bilbao.

Table 1: Technical Data of the Faraday Cup.

| Parameter | Description |
|---|---|
| Beam Irradiation | 3.63 MeV - 62.5 mA |
| Peak Beam Power | 230 kW |
| Average Beam Power | 16 W |
| Temperature | Body Cup 5-200 ºC<br>Actuator System 5-50 ºC |
| Vacuum Conditions | $10^{-7}$ to $10^{-10}$ mbar |
| Refrigeration | 25 ºC, 5 bar, 2 l/min |
| Faraday Cup Weight | ~10 kg |
| Body Cup Weight | ~1 kg |
| Body Cup Materials | Graphite Collector<br>Stainless Steel Body<br>Copper Repeller<br>Alumina/Macor Insulators |
| Mounting Orientation | 45º |
| Mounting Flange | CF100 |
| Mounting flange to beam axis distance | 273 mm |
| Mounting Flange Aperture | 86x58 mm |
| Body Cup Diameter | 70 mm |
| Body Cup Aperture | 48 mm |
| Stroke Distance | 80 mm |
| Repeller Voltage | 1000 V |
| Collector Signal Connection | BNC or SMA |
| Repeller Power Supply Connection | MHV |
| Pneumatic Actuator | 5-10 bars |
| Automatic Actuator Retraction | Spring > 250 N |
| Machine Protection System Limit Switchers | Integrated in the frame |
| Local Control Limit Switchers | Integrated in actuator |

## 2.1. List of Components

In Table 2 the components of the conceptual design are listed. The contractor could use the proposed components or choose equivalent products from other suppliers.

The in-vacuum components will operate in Ultra High Vacuum conditions of $10^{-7}$ to $10^{-10}$ mbar [1]. All materials to be used in vacuum need to be approved by ESS-Bilbao. For more information the contractor can consult "ESS Vacuum Handbook Part 3 - ESS Vacuum Design & Fabrication" [2], where some guidelines for design and fabrication of the in-vacuum components is provided.

Table 2: List of components of the conceptual design.

| Component | SubComponents | Proposed Component |
|---|---|---|
| Vessel **(Out of the scope)** (MEBT-FC-2000-ESS) | | |
| Faraday Cup (MEBT-FC-1000-ESS) | | |
| Body Cup *(in vacuum)* (MEBT-FC-1100-ESS - *CAD Model & blue prints*) | Steel Body | SS316L |
| | Graphite Collector **(Out of the scope)** | SGL R7550 |
| | Copper Wall Collector | Copper OFHC |
| | Repeller | Copper OFHC |
| | Alumina Insulator | Alumina 99% |
| | Macor Insulators | Macor |
| | Lid | SS316L |
| Actuator System (MEBT-FC-1200-ESS - *CAD Model*) | Body Cup Connections *(in vacuum)* | - Refrigeration: ϕ6 mm<br>- Repeller Voltage: Allectra 380-MHVor equivalent<br>- Data Signal: Allectra 311-KAP50or equivalent |
| | CF100 Flange *(in vacuum)* | DN 100-40 CF Flange. Pfeiffer 420FLR100-040 or equivalent |
| | Vacuum Bellow *(in vacuum)* | CF40, 8mm stroke vacuum bellow. Vacom EWB40R-80 or equivalent. |
| | Vacuum Plate *(in vacuum)* | - CF40 flange<br>- Refrigeration feedtrough: ϕ6 mm<br>- Data Signal feedtrough: Allectra SMA 50 Ω or equivalent<br>- Repeller Voltage feedtrough: Allectra 241-MHV or equivalent |
| | Vacuum Plate Connections | Hosing, cabling 200 mm |
| | Guides | - Guides NIM12SS-0300 or equivalent<br>- Linear Bearings SFPM12 or equivalent |
| | Fixed Plate | Stainless Steel ϕ150 |
| | Pneumatic Actuator | - Cylinder: Festo DSCB, DNC or equivalent<br>- Electrovalve: Festo CPE or equivalent<br>- Limit Switcher: Festo SME or equivalent |
| | External Limit Switchers | OMRON SS-01GL2-E or equivalent |
| | PPS Cover | Plastic cover ϕ150 mm |

As it is not always possible to make a precise and intelligible description of all the components of the Faraday Cup, some brands and / or types are described in the Technical Specifications and annexes.

All references in the Faraday Cup Technical Specifications and annexes to trademarks, goods or specific technical specifications must be understood in the sense of "art. 117.4 del Texto Refundido de la Ley de Contratos del Sector Público". The tenderer may propose other components as long as they comply with the technical requirements.

## 2.2. Body Cup

The body cup will be manufactured and assembled following the design supplied by ESS-Bilbao as blue prints. Any change proposal from the contractor should be notified to ESS-Bilbao for approval.

In Figure 2 we show the main components of the Faraday Cup Body Cup. The body cup will have a modular design that allows to unmount the different components, specially the graphite collector.

The body cup includes the following components:

- Refrigerated **steel body.**
- An **alumina insulator** will be placed between the graphite collector and the cooled steel body. Alumina is chosen due to its good thermal conductivity over other insulators such as macor.
- The manufacturing of graphite collector is out **of the scope** of the contract, and will be supplied by ESS-Bilbao. The dimensions of the graphite collector to be supplied by ESS-Bilbao are described in the supplied CAD model and drawings.
- A **copper wall collector** is included in order to collect transversal electron and to make an easy connection for the collector cabling. From the copper wall collector, the data signal will be extracted.
- A **copper repeller** operating at a maximum voltage of -1000 V.
- **Macor insulator:** guarantees insulation of the repeller and the copper wall collector.
- A collimator **lid** encloses all the body cup component. The lid should exert a force of at least 500 N on the cup.

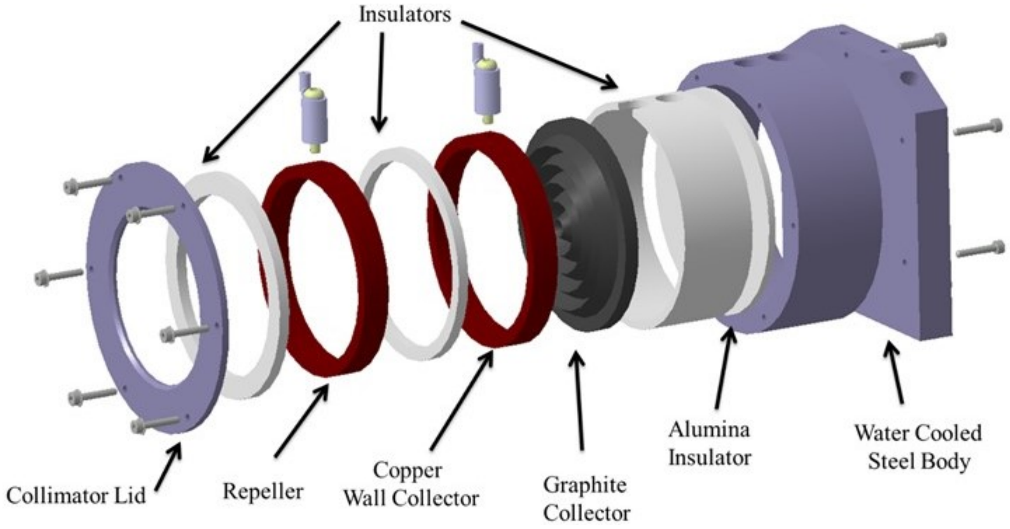


Figure 2: Main components of the Faraday Cup Body Cup.

## 2.3. Actuator System

The conceptual design for the actuator system is included as a reference. The design is included in the attached CAD model and is summarized in Table 2. Next we describe in more detail some components of the actuator system.

### 2.3.1. Vacuum Plate

The Vacuum plate could be connected to the vacuum bellow with a CF40 flange. In the CF40 flange the feedthrough for refrigeration, collector signal and repeller power supply will be included.

The actuator piston could connect the vacuum plate to the actuator. An extension to the CF40 flange may be included in order to support the guide bearings. In Figure 3 the proposed design for the vacuum plate is shown.

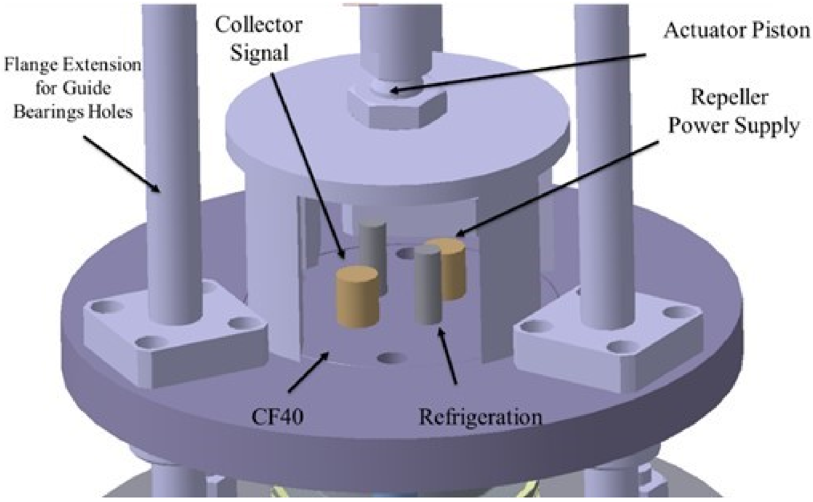


Figure 3: Proposed design for the vacuum plate. The figure shows the CF40 flange, actuator piston, feedthroughs and flange extension for the guide bearings.

### 2.3.2. Pneumatic Actuator

In Figure 4 we show the position of the Faraday Cup in a) retracted and b) inserted position.

The FC will be actuated with a pneumatic actuator, controlled by an electro-valve. The actuator system will have the following characteristics:

- The actuator will operate with compressed air 5-10 bars.
- The actuator stroke will be of 80 mm. A piston diameter of $\phi$ 40 mm is proposed.
- The actuator will by default be in the retracted position (see Figure 4).
    - Automatic retraction to protect the cup is required in case of failure. The retraction will be done with a spring. The spring would be included in the actuator cylinder pushing the piston retracted position in case of failure. The force of the spring should be of at least 250 N.
- A pair of limit switchers shall be installed on the FC actuator for the motion control system. The limit switchers will measure the beginning and end positions of the piston.
- The electro-valve will operate with a voltage of 24 V.
- The limit switchers will operate with a voltage of 30 V.

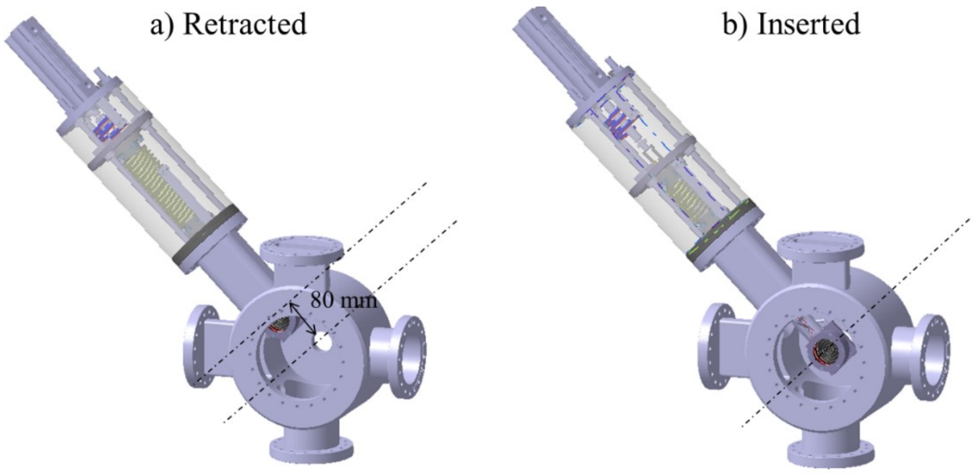


Figure 4: Scheme showing the Faraday Cup in a) Retracted and b) inserted position (right).

2.3.2.1. Actuator Force

For further information, we include the calculation of the required spring force.

The actuator diameter is 40 mm and the ambient pressure is P=0.1 MPa. Therefore, for automatic retraction the force should be:

$$F = P \cdot A = P \cdot \pi \frac{D^2}{4} = 0.1 \frac{N}{mm^2} \cdot 1256\, mm^2 = 125\, N$$

Assuming the spring also has to lift the Faraday Cup we should also consider the weight. An upper estimation for the weight to be lifted is 4 kg.

$$F = W = 4\, kg \cdot 10 \frac{m}{s^2} = 40\, N$$

In order to have a conservative system the spring force should be higher than 250-500 N.

### 2.3.3. External Limit Switchers

An additional pair of switchers will be installed in order to detect the position of the FC. This pair of switches will be cabled separately and used solely by the Machine Protection System (MPS) of ESS.

The switches are required to detect when the cup is parked in a safe position (retracted) or intercepting the beam trajectory (inserted), see Figure 4. They might be mounted in supports that correspond to the beginning and end positions of the vacuum plate.

The external limit switchers will be completely independent from the limit switchers integrated in the actuator. Both pairs of limit switchers (external and actuator) will be designed to have identical response, eg. the inserted/retracted status will appear simultaneously.

## 2.4. Faraday Cup Mounting

The Faraday Cup will be connected to a CF100 flange that has a port of 58x86 mm placed 273 mm from the MEBT beam axis (see Figure 5).

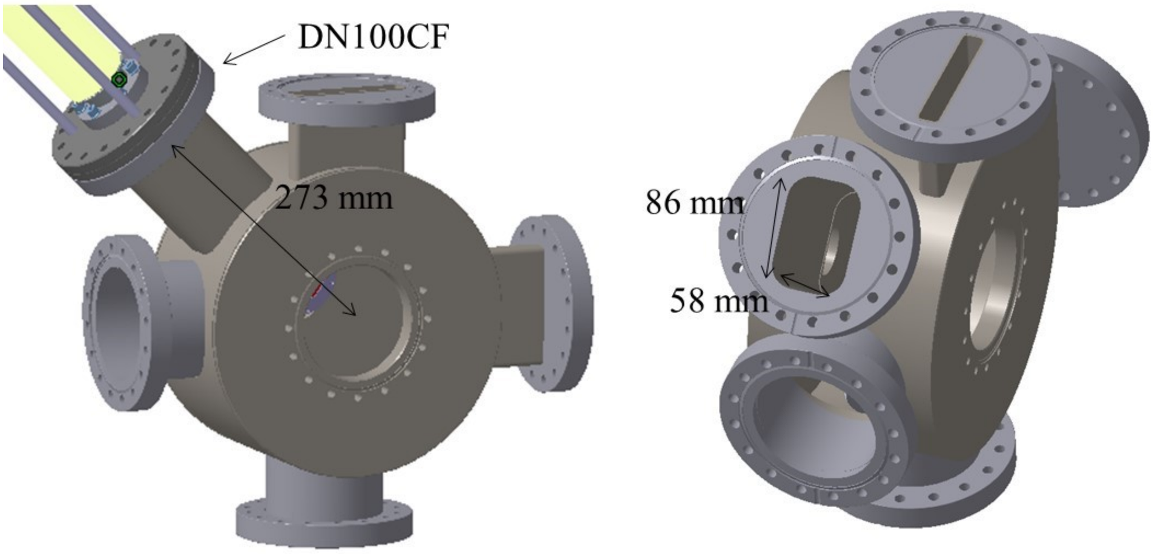


Figure 5: Vessel S10 where the Faraday Cup is mounted. The main dimensions of the Faraday Cup are given. The supply of the Vessel is out of the scope of the contract; the vessel will be supplied by ESS-Bilbao.

## 2.5. Positioning

The final assembly will guarantee that the position of the Faraday Cup Body Cup in the vessel is in a range of ± 1 mm of the MEBT beam axis.

The system should be able to adjust the final position of the Body Cup in a range of ± 5 mm from the beam axis.

In Figure 6 we show a possible design for positioning of the Faraday Cup. The contractor can propose an alternative proposal as long as it allows for a fine positioning of the system.

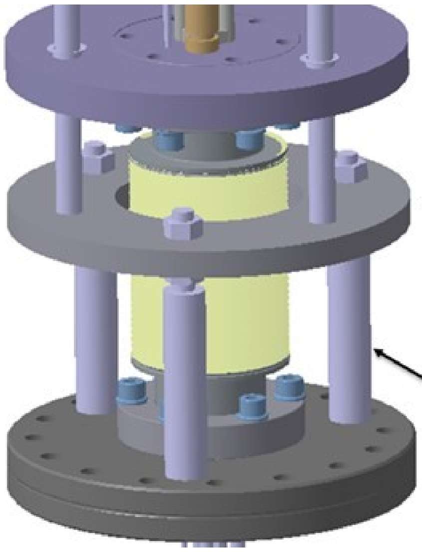


Figure 6: Proposed designs for the port aligner of the FC. Design based on the positioning of and adjustable plate using stud bolts.

## 2.6. Materials

Provided CAD model includes selected materials (steel, copper, alumina), any change in the materials selected must be approved by ESS-Bilbao. The contractor shall supply ESS-Bilbao full information about the material specifications used in the different components. The materials shall be specified and qualified according to internationally recognised standards.

### 2.6.1. In-Vacuum Materials

The following materials will be used for the in-vacuum components:

- Stainless Steel SS316L.
    - SS304L, SS316Ti could be used if approved by ESS-Bilbao.
- Copper OFHC (phosphorous de-oxidized grade shall not be used)
- High purity alumina >99%
    - High purity alumina is preferred due to its higher thermal conductivity.
    - Alumina with purities >90% could be used if approved by ESS-Bilbao.
- Machinable glass (Macor)
- Kapton Wires

Any other materials used in in-vacuum components should be firstly approved by ESS-Bilbao.

As specified by the ESS Vacuum Handbook Part 1 [1], the following materials are specifically prohibited for in-vacuum components:

- Brass,
- Standard Hard Solder,
- All Plastics,
- Free cutting stainless steel,
- Silicon or sulphur based machining lubricants when machining any components (only water-soluble machining lubricants are permitted),
- Any material containing: Zinc, Cadmium, Phosphorus, Sodium, Selenium, Potassium or Magnesium.
- Soft Solder,
- Electrical Solder,
- ASTM type 303,
- All Glues, Greases,
- GE Varnish, Anodized surfaces or any mechanically polished components,

### 2.6.2. Safety Requirements for materials

In order to minimize fire risks and radiological hazards, several materials are prohibited inside the ESS accelerator tunnel. In Table 3 the list of allowed/not allowed materials due to fire safety requirements is given and in

Table 4 a list of materials to be avoided due to their high radiological hazard is given.

For a reference the contractor can consult "Safety request form – ESS-0063691" [3].

Table 3: List of allowed/not-allowed materials with respect to fire safety.

| Classification | Material | Abbreviation | Material | Abbreviation |
|---|---|---|---|---|
| Suitable Base Materials | Melamine formaldehyde | MF | Polyether ether ketone | PEEK |
| | Phenol formaldehyde | PF | Polyether imide | PEI |
| | Polyamide imide | PAI | Polyimide | PI |
| | Polyarylate | Par | Urea formaldehyde | UF |
| | Polybenzimidazole | PBI | | |
| Suitable only with incorporation of fire retardant NOT containing halogen, sulphur and phosphorus | Epoxy resin | EP | Polycarbonate | PC |
| | Ethyl acrylate rubber | EAR | Polyethylene terephthalate | PET (PETP) |
| | Ethylene propylene diene | EPDM | Polyiscocyanurate | PIR |
| | Ethylene propylene rubber | EPR | Polyphenylene ether | PPE |
| | Ethylene vinyl acetate | EVA | Polyphenylene oxide | PPO |
| | High density polyethylene | HDPE | Polypropylene | PP |
| | Low density polyethylene | LDPE | Polyurethane | PU |
| | Polyamide | PA | Polyvinyl acetate | PVAC |
| | Polyaryl amide | PAA | Polyvinyl alcohol | PVA |
| | Polybutylene | PB | Silicones | SI |
| | Polybutylene terephthalate | PBT | | |
| Prohibited materials | Acetal | POM | Polyoxymethylene | POM |
| | Acrylonitrile | AN | Polystyrene | PS |
| | Acrylonitrile butadiene styrene copolymer | ABS | Polytetrafluoroethylene | PTFE |
| | Acrylonitrile styrene acrylic ester copolymer | ASA | Polyvinyl chloride | PVC |
| | Ethylene tetrafluoroethylene copolymer | ETFE | Polyvinyl fluoride | PVF |
| | Natural rubber | | Polyvinylidene chloride | PVDC |
| | Perfluoroethylene propylene | FEP | Polyvinylidene fluoride | PVDF |
| | Polychlorotrifluoro ethylene | PCTFE | Styrene acrylonitrile copolymer | SAN |
| | Polymethyl methacrylate | PMMA | Styrene butadiene copolymer | SB |

Table 4: List of materials considered as highly critical due to their high radiological hazard.

| Critical elements | Critical elements | Critical elements |
|---|---|---|
| Antimony | Hafnium | Tantalum |
| Cadmium | Iridium | Terbium |
| Cesium | Lithium | Thorium |
| Cobalt | Scandium | Uranium |
| Europium | Silver | Xenon |
| Gold | Strontium-90 | |

## 2.7. Machining

According to ESS Vacuum Handbook specifications [2], no lubricant shall be used which might result in material contamination that cannot be removed by the cleaning methods used by the process described here. The use of cutting fluids or lubricants, which contain sulphur or silicone compounds are prohibited. Only water-soluble oils shall be used for machining.

In order to facilitate cleaning preparations for vacuum, machining liquids shall be silicone and halogen free. Surfaces shall be milled or turned, grinding or any other mechanical abrasion must be first approved by ESS-Bilbao.

## 2.8. Mechanical Tolerances

The contractor will be responsible of choosing the tolerances to assure that the technical specifications of the product are satisfied.

The contractor will include the mechanical tolerances in the blueprints of the components of the Faraday Cup.

## 2.9. Welding

The welding will be done by certified professional welders and will be executed according to ISO standards for steel. TIG is the the preferred welding method, the use of other type of welding or brazing processes will be notified to ESS-Bilbao for approval.

Standards that apply to welding procedures are:

- ISO 9606-1: 1994 Approval testing of welders — Part 1 : Steels
- ISO 15614-1: 2004 Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys
- ISO 5817: 2005 Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections

For a reference the contractor can consult methods and design on in-vacuum components the sections 3.2.3 & 3.2.4 of the “ESS Vacuum Handbook Part 3 - ESS Vacuum Design & Fabrication” [2].

## 2.10. Mechanical Joining

For in-vacuum components, the hardware used in the mechanical joining (screws, bolts, studs, washers, nuts) should be silver plated and especially suitable for vacuum applications. Vacom

Vacuum Compatible Screws[2] or similar hardware is proposed for the design of the FC. The different mechanical joining will be designed in order to avoid the presence of gas traps. Therefore, blind holes should be avoided if possible. When using blind holes, vented screws will be used.

For in-vacuum refrigeration the use detachable joinings (VCR, Ultra-torr) should be informed to ESS-Bilbao for approval.

### 2.11. Cleaning

Before delivery to ESS-Bilbao, all components shall be cleaned in order to be ready for assembly. All surfaces shall be rendered free from contamination, grease, swarf, hydrocarbons or any other impurities.

The inside and outside surfaces of applicable components must be clean, smooth and free from scratches. This surface state shall be preserved during handling of the components.

For a reference the contractor can consult cleaning procedures on Section 4.2 of the "ESS Vacuum Handbook Part 3 - ESS Vacuum Design & Fabrication" [2].

### 2.12. Storage, Packing and Shipping

The Contractor is responsible for the storage, packing and the transport to ESS-Bilbao. He shall ensure that the equipment is stored in an area that the state of the components is not altered, that it is packed such that it is delivered to ESS-Bilbao without damage and any possible deterioration in performance due to transport conditions.

For a reference the contractor can consult handling transport description on Section 4.5 of the "ESS Vacuum Handbook Part 3 - ESS Vacuum Design & Fabrication" [2].

[2] https://www.vacom.de/en/products/vacuum-suitable-screws

# 3. Acceptance Plan

## 3.1. General Directives

The contractor will follow the next EU directives for the design and manufacturing of the product:

- Machinery 2006/42/EEC
- Electromagnetic Compatibility 89/336/EEC
- Low Voltage 2006/95/EEC

## 3.2. Materials

The contractor shall include documentation of all the chosen material, including the mechanical properties and chemical composition.

## 3.3. Vacuum Leak Test

A vacuum leak test will be done by the contractor. The contractor will guarantee that all fabricated parts shall be helium leak tested and show no detectable leak $>1x10^{-9}$ mbar l $s^{-1}$ . For a reference the contractor can consult Leaking Test description on Section 3.2 of the "ESS Vacuum Handbook Part 4 – Vacuum Test Manual" [4].

The cooling lines of the FC should undergo a bake-out between water pressure tests and leak tests. The bake out is necessary to remove the water that, freezing during the pump down, could create a temporary barrier and make eventual leak undetectable. The test sequence should be: water pressure test, bake-out (100 ºC for 12 hours), leak detection.

The contractor will inform about the procedure chosen for the vacuum leak test for approval by ESS-Bilbao.

## 3.4. Verifications done by ESS-Bilbao

Prior to the acceptance of the product, its compliance with the technical specifications could be validated by ESS-Bilbao. For the validation, different acceptance tests would be done in a month after the delivery of the product to ESS-Bilbao.

The contractor will be informed if the product does not comply with some of the requirements. In that case, the contractor may be required to send an inspector to ESS-Bilbao in order to verify the product. All the parts that are deemed un-satisfactory will be returned to the contractor for its reparation or substitution. In those cases, a plan will be developed jointly by ESS-Bilbao and the contractor in order to find a solution.

Next there is a description of several acceptance tests that could be performed by ESS-Bilbao:

- Pressure Tests
  - The refrigeration circuit is pressurized up to 16 Bar in order to assess correct assembly of the different components. The test will take a duration of at least 15 min. After the test the channel will be emptied and dried with compressed air.
- Electric Tests
  - A test on the collector signal cable. The test assesses the cable connections are correctly done and no current loss or parasitic current is observed. This test will be done with an external voltage/source directly on the graphite or copper collector. The tests will guarantee that the current from the collector is the same as measured in the external BNC/SMA port. The tests will be done with the nominal current of 62.5 mA.
  - A test that guarantee that the repeller is properly insulated. The electric insulation test will be done with a voltage of 1 kV. The leaked current shall be less than 1 mA (insulation resistance > 1 MΩ). During the test special attention should be paid to the first microseconds where the transient phenomena take place. In order to observe transients an oscilloscope will be used.
  - The duration of electrical tests would be of 10 minutes in order to guarantee proper operation in the steady state. In the test it is important to measure and document the humidity and temperature conditions. The test results could be used later for maintenance purposed and knowing in detail the test conditions is necessary.
- Motion Tests
  - A motion test of the full assembly in its final position (45º from the vertical). The test assesses proper operation of the actuator system and correct assembly of the different components. The test also assesses that the position of the body cup in respect to the beam axis complies with the required tolerances.
- Other Tests: ESS-Bilbao reserves the right to perform any other tests in order to assess that the delivered product complies with the required specifications.

## 4. Project Schedule & Deliverables

In Table 5 the project schedule and project deliverables are presented.

The acceptance of the product by ESS-Bilbao will be done once all the deliverables have been received and ESS-Bilbao assess that the product complies with the requirements specified in the *Technical Specifications*. The contractor will supply the required documentation in a period of five days after the product delivery.

The documentation will be delivered both in physical and electronic format (pdf). Blue-prints can be supplied in electronic format (pdf, DXF) and in CAD formats (Cadpart, stp, igs).

Table 5: Project Schedule for the ESS MEBT FC

| **Concept** | **Deliverables** | **Responsible** | **Deathline** |
|---|---|---|---|
| Contract Signature | Conceptual Design: ESS-Bilbao will supply the CAD conceptual design to the contractor. | ESS-Bilbao & Contractor | T0 |
| Detailed Design | Detailed Design Documentation: Blue-prints, description of the components and materials specifications | Contractor | T1=T0+2 months |
| Detailed Design Approval | | ESS-Bilbao | T2 = T1 + 2 weeks |
| Product Delivery | Faraday Cup Product | Contractor | T3= T2 + 3 months |
| | Product Documentation: Blue-prints, description of the components and materials specifications | | |
| | User's Guide / Safety Instructions: description of the operation of the product and safety measures | | |
| Product Acceptance | | ESS-Bilbao | T4 = T3 + 1 month |

# 5. Other Conditions

## 5.1. Project Follow-up

The contractor will assign a contact person that will be in charge of the technical execution of the contract and the follow-up during the contract duration. The contractor will supply required information regarding the product design and manufacturing at request of ESS-Bilbao.

## 5.2. Components, design and operation responsibility

The contractor is responsible of the correct operation of all the components from the product delivery till the guarantee expires. The approval of the design from ESS-Bilbao does not exempt the contractor from its responsibility.

## Contact

| Name | Phone Number | E-mail |
|---|---|---|
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| Ibon Bustinduy | +34 94 607 68 51 | ibustinduy@essbilbao.org |

## References

[1] G. Hulla, "ESS Vacuum Handbook Part 1 – General Requirements for the ESS Technical Vacuum System," Handbook 0, May 2014.

[2] G. Hulla, "ESS Vacuum Handbook Part 3 - ESS Vacuum Design & Fabrication," Handbook 0, May 2014.

[3] D. Phan, L. Tchelidze, and M. Lindroos, "Safety request form – ESS-0063691 - List of allowed/not allowed materials to be incorporated in equipment to be installed in the accelerator tunnel," Internal ESS ESS-0063691, Jul. 2016.

[4] G. Hulla, "ESS Vacuum Handbook Part 4 – Vacuum Test Manual," Handbook ESS-0012897, Apr. 2016.